Air Curtain Incinerator
Emissions Factors Determination

From:	Brian Clerico, AQE II and Errol Villegas, Permit Services Manager
To:	Arnaud Marjollet, Director of Permit Services
Date:	April 04, 2017
Re:	Recommendation for Air Curtain Incinerator Emission Factor Determination for Woody Biomass from Agricultural Sources and Forest Vegetation

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The purpose of this memo is to examine available test data and recommend emission factors appropriate for an air curtain incinerator (ACI) burning woody biomass derived from agricultural sources and forest vegetation.

1. BACKGROUND

The San Joaquin Valley is a large agricultural region that annually generates hundreds of thousands of tons of woody biomass debris primarily from the pruning and removal of orchards and vineyards. The main historical disposal option for this material has been open burning, but open burning of ag waste has been curtailed by 80% since 2003, largely made possible by the availability of the option of chipping the material and sending it to a nearby biomass power plant.

In recent years, as the biomass power industry has lost its financial and societal support and decreased in numbers from 15 facilities to five today (with none of the five buring much ag waste), the San Joaquin Valley has accumulated a glut of wood material in need of disposal. This excess has been exacerbated by California's recent extreme drought and the bark beetle infestation which has resulted in over 100 million dead trees in the State, mostly in the southern Sierra Nevada, which is in the Valley Air District. For areas where the buildup of wood material has become an acute hazard, air curtain incinerators (ACIs) have become an important disposal option. Within the San Joaquin Valley, CalFire is currently using ACIs for wildfire hazard reduction in forested areas, and an almond huller has received an Authority to Construct to install an ACI to dispose of an accumulation of wood sticks from their almond processing operation. To quantify emissions from ACIs for purposes of permitting and emissions inventory, the most representative emission factors should be used. This memo is intended to identify and recommend the most representative emission factors for ACIs burning woody biomass from agricultural sources and forests.

A number of emission tests have been conducted on ACIs. A table of the emission factors derived from those tests is provided in Table 1 below along with the emission factors for open burning of almond orchard residues and biomass power plants for comparison in Table 2.

In selecting the most representative emission factors, the District was guided by the following considerations:

(1) A limited number of emissions tests have been published to date;
(2) The source test results published show a wide variance;
(3) Air curtain incineration may be regarded as a controlled form of open burning;
(4) The PM10, CO, and VOC emission factors for open burning show a high degree of dependence on the material burned;
(5) The ARB open burn emission factors for agricultural orchard and vine residues provide an upper bound for PM10, CO, and VOC because the visual evidence indicates the ACI is performing significantly better at reducing smoke and visible particulates (and, by extension, other products of incomplete combustion such as PM10, CO and VOC) than open burning of woody biomass derived from agricultural or forest vegetation. The open burn emission factors for almond orchards will be used in Table 2 to represent a type of woody agricultural residue common in the San Joaquin Valley;
(6) The emission factors for biomass power plants controlled by a fabric filter provide a lower bound for PM10 (0.089 lb-PM10/ton)[1];
(7) SOx emissions are entirely material dependent; thus, the open burn SOx emission factors for agricultural orchard and vine crops, or for forests, are also likely the most representative for ACIs.

The emission factors from Table 1 (page 3) were evaluated using the criteria listed above.

A. AP-42, 2.1-12, J.O. Burckle Test from Table 1 (NOx and PM10)

The current AP-42 emission factors for the incineration of wood (cord wood) are based on a pilot scale study from 1968. The unit tested was not a functional ACI but a pilot scale version constructed for the purpose of emissions testing. The maximum temperature reached by the pilot scale firebox was 1,300 ^{0}F, which is approximately 300 to 900 ^{0}F less than an ACI in the field. The PM10 emission factor resulting from this study is higher than the ARB and AP-42 PM10 emission factors in Table 2 for the open burning of almond orchard wood, which is a representative type of orchard wood waste for the San Joaquin Valley. The NOx emission factor obtained was 4 lb-NOx/ton, which is much higher than any of the tests on actual ACIs and similar to open burn emission factors for NOx from Table 2.

[1] The seven most recent source tests for the biomass power plants Merced Power and Ampersand Chowchilla showed an average PM10 emission rate of 0.089 lb-PM10/ton. This average source test value is a more representative estimate of the PM10 emissions from biomass plants than the permitted value (0.61 lb-PM10/ton). As a comparison, a boiler fired on dry wood with a heating value of 7,610 Btu/lb has an uncontrolled emission rate of 5.5 lb-PM10/ton (Table, 1.6-1), which is approximately the same emission factor for open burning of orchard agricultural residues.

The emission factors from this study were not considered representative for an ACI burning woody biomass derived from agricultural sources or forests for the following reasons:

(1) The unit tested was not an actual ACI;
(2) The maximum combustion temperatures were lower than a typical ACI;
(3) The AP-42 ACI PM10 emissions factor is higher than the open burn PM10 emission factors for most agricultural sources (Table 2); and
(4) The NOx emission factor is significantly higher than any of the air curtain tests (note that lower combustion temperatures would be expected to lead to lower NOx emissions, adding an additional degree of caution regarding the results of this test).

2. ASSESSMENT OF SOURCE TESTS RESULTS

Table 1 below summarizes the emission factors derived from source tests conducted on ACIs. For comparison, Table 2 summarizes the generally accepted emission factors for open burning and for biomass power plants.

Table 1 - Emissions Test Results of Air Curtain Incinerators

Test	Material	Year	NOx (lb/ton)	SOx (lb/ton)	PM10 (lb/ton)	CO (lb/ton)	VOC (lb/ton)	Notes
AP-42, 2.1-12, J.O. Burckle	Wood and cord wood	1968	4	-	13	-	-	Pilot Scale Box Trench Burner, Max temp 1,300 F.
Fountainhead Engineering, Michigan	Wood	2000	Not reported*	Not reported	0.12	1.1	Not reported	Modified EPA Methods.
USDA, Baker Oregon, (Air Curtain S-217)	**Forest vegetation**	**2002**	Not measured	Not measured	**1.1 (PM2.5)**	**2.6**	**1.1**	**Missoula Fire Science Lab**
USDA, San Bernardino (McPherson M30)	**Forest vegetation**	**2003**	**Not measured**	**Not measured**	**1.4 (PM2.5)**	30	**0.6**	**Missoula Fire Science Lab**
BC Hydro, Jordan River British Columbia	Wood	2003	0.04	0.0031	0.13	0.61	0.11	Modified EPA Methods and Canadian Methods
Victoria, Australia	Wood	2016	0.27	0.23	0.0064	4.2	0.096	(US)EPA Methods
US EPA – Hurricane Katrina	Vegetative material	2016	1.6	0.49	7.7	6.9	0.41	See Attachment A, Table 5-1 for NOx, SOx, CO, and VOC; Table 5-4 for PM10

* The Victoria, Australia test indicated the Fountainhead test showed 0.05 lb-NOx/ton, but this was not confirmed by the Valley Air District.

Table 2 – Emission Factors for Biomass Open Burn and Biomass Power Plant

Source	Material	Year	NOx (lb/ton)	SOx (lb/ton)	PM10 (lb/ton)	CO (lb/ton)	VOC (lb/ton)	Notes/ Documentation
Open Burn – ARB	**Almond**	1992	5.9	**0.1**	7.0	52	5.2	ARB Memo
Open Burn – ARB	Forest	Not indicated	3.5	0.1	19 - 30	154 - 312	8 - 21	ARB Memo
Open Burn – AP-42	Almond	1974	-	-	6 (PM)	46	6	AP-42, Table 2.5-5
Open Burn – AP-42	Forest	1995	4 (est.)	-	17	140	19	AP-42, Table 2.5-5
Merced Power (N-4607-8) & Ampersand Chowchilla (C-6923-3)	Biomass	-	1.2 (1.1)	0.61 (0.033)	0.61 (0.089)	0.87 (0.25)	0.076	Permitted EFs (top) and average of seven source tests (indicated in parentheses) of two active biomass power plants

B. Fountainhead, Table 1 (PM10, CO)

The Fountainhead study was conducted in October, 2000 in Clarkston, Michigan using a Whitton Model S-127 ACI having a 15-18 ton per hour capacity, burning wood debris. The nature of the wood debris is not described, but the location of the test is in a forested region of Michigan. The test will therefore be considered in this analysis to establish representative emission factors for agricultural sources and forest vegetation.

The PM10 emission factor (0.13 lb-PM10/ton) from the Fountainhead test is only slightly greater than the average PM10 emission factor (0.089 lb-PM10/ton) measured from the seven most recent source tests of the biomass power plants Merced Power (N-4607-8) and Ampersand Chowchilla (C-6923-3), which have a fabric filter for PM10 control. The fabric filter has been established as the highest level of PM10 control for biomass combustion through extensive emissions testing with District oversight. In general, fabric filters are expected to achieve at least 99% control for PM10.

For open burning of almond orchard wood, the accepted PM10 emission factor is 7.0 lb-PM10/ton. When compared to the 0.13 lb-PM10/ton emission factor from the Fountainhead test, the ACI would appear to have achieved over 98% control efficiency, which is comparable to the fabric filter control efficiency rate used to control biomass combustion emissions. The District at this point does not believe that sufficient information is available to overrule the District's doubt that an ACI can achieve a nearly equal level of PM10 emission control as a high efficiency fabric filter.

For instance, ACIs are known to have visible emissions during the approximately 10 - 30 minute start-up period before the air curtain is engaged, when the combustion process is presumably roughly equivalent to an open burn. Also, when new material is added to the firebox, the flow of the air curtain is broken, and the ACI emits a puff of smoke. The fabric filter does not have such gaps associated with its effectiveness as a PM10 control device. Moreover, it is uncertain whether the emission factor adequately accounts for the periodic puffs of smoke from loading because the sampling probe is positioned for the maximum firebox exit velocity during steady-state operation of the air curtain, which is usually at the edge of the firebox opposite the air manifold, whereas the puff of smoke occurs above the material drop point, typically more toward the middle of the firebox.

These considerations lead one to believe that the ACI emission factor for PM10 should be higher than the biomass power plant emission factor for PM10.

C. BC Hydro, Table 1 (NOx, SOx, PM10, CO, and VOC)

The BC Hydro study was conducted in March, 2003 in Jordon River, British Columbia using an Air Burners Inc. Model S-116 ACI loaded between 4 – 8 metric tonnes per hour, burning wood debris. Although the nature of the wood debris is not described, the location of the test is in a forested region of British Columbia. The test will therefore be considered in this analysis to establish representative emission factors for agricultural sources and forest vegetation.

Similar to the Fountainhead results, the PM10 emission factor from BC Hydro (0.12 lb-PM10/ton was roughly equivalent to the average PM10 emission factor from biomass power plants. As discussed above, the District believes that the ACI emission factor for PM10 is likely higher than the fabric filter controlled biomass power plant emission factor for PM10.

The BC Hydro test also reported a NOx emission factor (0.04 lb-NOx/ton) that is significantly lower than the average emission factor (1.1 lb-NOx/ton) from seven recent source tests conducted on the biomass power plants using selective non-catalytic reduction (SNCR) with ammonia injection as a NOx control. NOx reduction levels from SNCR range from 30 to 50% according to EPA's Fact Sheet (EPA-452/F-03-031). It follows then that the BC Hydro NOx emission test would appear to represent a 99% reduction in NOx compared to open burn and a 96% reduction compared to the biomass boiler already controlled by SNCR.

Two possible explanations for the lower NOx emission factors from the ACI tests are that the biomass power plants burn plant material that is higher in nitrogen (i.e. fuel NOx) or that the boiler operates at a higher combustion temperature (i.e. thermal NOx). An analysis of the nitrogen content of the plant material burned in the biomass boiler versus the nitrogen content of the plant material burned in the ACI would need to be performed to establish that the fuel is the source of the difference in NOx emissions.[2] A comparison of peak operating temperatures does not suggest that the air curtain would produce less thermal NOx. Biomass boilers may reach temperatures of 1,850 ^{o}F; whereas an ACI can reach temperatures over 2,000 ^{o}F. Factors other than temperature, such as residence time in the combustion hot zones, may account for differences in thermal NOx emissions, but the District is not aware that this speculative explanation has been demonstrated. These considerations lead the District to believe that the NOx emission factor for an ACI should be significantly higher than recorded in this test.

D. Victoria, Australia, Table 1 (NOx, SOx, PM10, CO, and VOC)

The Victoria study was conducted in February, 2016 at a recycling plant. The material burned was "clean" wood, i.e. vegetative material and uncoated wood pallets, at a rate of 4.2 metric tonnes per hour. Therefore, this source test will be considered in this analysis to establish emission factors for agricultural sources and forest vegetation.

The PM10 emission factor from the Victoria test (0.0064 lb-PM10/ton) was significantly lower than the average PM10 emission factor (0.089 lb-PM10/ton) measured from biomass power plants. For the reasons discussed above, this PM10 emission rate cannot be used at this time.

[2] Extensive Operating Experiments on the Conversion of Fuel-Bound Nitrogen into Nitrogen Oxides in the Combustion of Wood Fuel, *Forests* **2017**, 8, 1. For timber wood having nitrogen content between 0.04 and 1.2%, the conversion of nitrogen to NOx ranged from approximately 66% to 15%, respectively, i.e. the rate of nitrogen to NOx conversion decreased exponentially with increasing nitrogen content.

The Victoria test also reported a NOx emission factor (0.27 lb-NOx/ton) that is significantly lower than recent source tests conducted on the biomass power plants using selective non-catalytic ammonia injection as a NOx control. Similar to the BC Hydro test results, the District believe that the NOx emission factor for an ACI should be significantly higher than recorded in this test.

E. USDA, Baker, Oregon from Table 1 (PM10, CO, and VOC)

USDA performed an ACI emission study in October, 2002 in Baker, Oregon, using an Air Curtain Inc. Model S-217 ACI, having a capacity of 6 tons per hour. The material burned was Ponderosa Pine trees. The test will therefore be considered in this analysis to establish representative emission factors for agricultural sources and forest vegetation.

The PM10 emission factor obtained from the USDA Baker, Oregon test is 1.15 lb-PM10/ton, which is the third highest PM10 emission factor of all the source tests conducted on actual ACIs.

The USDA source tests measured PM2.5. This was converted into a PM10 emission factor by using the ratio of PM10 to PM2.5 from ARB open burn emission factors for almond agricultural residues. For almond agricultural residues, the ratio of PM10 to PM2.5 is 7.0 lb-PM10/ton to 6.7 lb-PM2.5/ton. Therefore 1.1 lb-PM2.5/ton × (7.0 lb-PM10/ton ÷ 6.7 lb-PM2.5/ton) = 1.15 lb-PM10/ton

This emission factor is an order of magnitude larger than the PM10 emissions measured for the biomass power plants (0.089 lb-PM10/ton), which are controlled by a fabric filter, and yet lower than the emission factor for open burning of almond wood (7.0 lb-PM10/ton), which is an uncontrolled source. As the ACI is a controlled form of open burning, it is reasonable that the PM10 emission factor for an ACI would be lower than the PM10 emission factor for open burning. Thus, the USDA emission factor for PM10 falls between the expected upper bound (uncontrolled open burning) and lower bound (biomass power plant with a fabric filter).

As PM10, CO and VOC are the products of incomplete combustion, acceptance of the PM10 emission factor implies an acceptance of the CO and VOC emission factors as well.

The USDA study did not include NOx or SOx emission factors.

F. USDA, San Bernardino from Table 1 (PM10, CO, and VOC)

USDA performed a second ACI emission study in June, 2003 in San Bernardino (Lake Arrowhead), California, using a McPherson Model M30 ACI burning forest vegetation. The burn rate (tons per hour) of the unit was not identified. The test will therefore be considered in this analysis to establish representative emission factors for agricultural sources and forest vegetation.

The PM emission factor obtained from the San Bernardino study is 1.46 lb-PM10/ton, similar to the Baker, Oregon study above.

The USDA source tests measured PM2.5. This was converted into a PM10 emission factor by using the ratio of PM10 to PM2.5 from ARB open burn emission factors for almond agricultural residues. For almond agricultural residues, the ratio of PM10 to PM2.5 is 7.0 lb-PM10/ton to 6.7 lb-PM2.5/ton. Therefore 1.4 lb-PM2.5/ton × (7.0 lb-PM10/ton ÷ 6.7 lb-PM2.5/ton) = 1.46 lb-PM10/ton

For CO, the reported emission factor was 30 lb-CO/ton, which is an order of magnitude higher than the CO emission factor reported for the Baker, Oregon study and more than four times larger than the next highest reported CO emission factor in Table 1.

The San Bernardino report includes tables comparing the Baker, Oregon results to the San Bernardino results. Those tables also show the CO emission factor for the Baker, Oregon study to be ten times larger, i.e. 26 lb-CO/ton than originally reported. It should be noted that the Baker, Oregon study and the San Bernardino study have different lead authors, and no mention is made in the report of USDA making a correction to the originally reported CO emission factor from the Baker, Oregon study. USDA has not responded to requests for clarification of this matter. Norbert Fuhrmann, Vice President of Air Burners, Inc. disputed the 26 lb-CO/ton emission factor in the San Bernardino report, stating that the originally reported value from Baker, Oregon of 2.6 lb-CO/ton was correct and that an error in the placement of the decimal had likely been made in the San Bernardino report. If Mr. Fuhrmann's contention is correct, the CO emission factors from the USDA studies would agree better with the other ACI CO emission factors reported in Table 1. Nevertheless, since USDA has not issued a correction for the San Bernardino CO emission factor, the District will regard the reported value of 30 lb-CO/ton as the official value from this study.

As noted at the beginning of this analysis, the District is primarily concerned with choosing the most representative emission factors for an ACI incinerating woody biomass derived from agricultural sources and forests. The CO emission factor reported in the San Bernardino study (30 lb-CO/ton) is roughly the same order of magnitude as the open burn emission factors in Table 2 for almond wood (e.g. 46 lb-CO/ton and 52 lb-CO/ton). Since the available data suggests that the ACI should perform an order of magnitude better than open burning for the products of incomplete combustion (i.e. PM10, CO and VOC), the CO emission factor from this study will not be considered representative for an ACI burning woody biomass derived from agricultural sources or forests.

In ATC project N-1162806, for an ACI burning almond sticks at an almond huller, the concern about the representativeness of the CO emission factor in the San Bernardino study extended to the other pollutants measured in that study (PM2.5 and VOC). One of the criteria for selecting emission factors in the ATC project was to accept or reject emission factor sets for PM10, CO and VOC because of the assumption that the emission factors of these pollutants are related as the products of incomplete combustion. Therefore, none of the reported emission factors from San Bernardino were used in the ATC project. However, since other emission factor sets of PM, CO and VOC have been evaluated based on the reported PM emission factor, and PM

emission factor from the San Bernardino study is comparable to the Baker, Oregon study, the District has now reconsidered the use of the PM and VOC emission factors from the San Bernardino study.

Therefore, in this memo, the District will include the PM and VOC emission factors from the San Bernardino study with the Baker, Oregon study as representative for the burning of woody biomass derived from both agricultural sources and forests.

The USDA study did not include NOx or SOx emission factors.

G. Assessment of EPA "Katrina" Study (NOx, SOx, PM10, CO, and VOC)

The District received a draft copy of EPA's *Managing Debris after a Natural Disaster: Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner: Source Emissions Measurement Results*, November 17, 2016 (see Attachment A). The study measured emissions and estimated emission factors for an ACI burning vegetative and construction and demolition debris in 2008 as part of the cleanup from Hurricane Katrina. Three test runs of the emissions from vegetative debris and three test runs for construction and demolition debris were measured separately.

Based on the District's analysis of EPA's document (Attachment B), the District concluded that the emission factors from EPA's study are likely overstated and cannot be found to be representative of the emissions from incineration of the agricultural or forest wood biomass in California. Therefore, the results of this test are not recommended to be used in future permitting actions for air curtain incinerators in the District and will not be discussed any further.

3. EMISSION FACTOR DETERMINATION

Based on the following reasons, a single set of ACI emission factors will be recommended for use for both agricultural wood (such as orchard pruning, almond sticks, orchard removals, etc) and forest vegetation (such as large parts of tree trunk, branches and other woody materials):

(1) There are no published ACI emission studies specific to agricultural wood; all the available ACI studies are based on forest vegetation or a mix of forest vegetation and generic wood (e.g. wood pallets).

(2) The USDA studies that are the basis of the PM10, CO, and VOC emission factors recommended in Table 3 below burned forest vegetation, with can be large sections of trunks and small wood. Among the ACI tests considered as potentially representative, the USDA studies produced the highest PM10 and VOC emission factors.

(3) The ARB (August 17, 2000 Memorandum) open burn emission factors for the products of incomplete combustion (i.e. PM10, CO, and VOC) are generally higher

for forest vegetation than for agricultural materials. Since ACI may be considered a controlled form of open burning, the same pattern present in the open burn emission factors may be expected in the ACI emission factors so use of emissions factors for forest debris is likely to conservatively overstate emissions from agricultural waste.

(4) The SOx emission factor is entirely material dependent, and the SOx emission factor for open burning orchard and vineyard residues is the same as for forest vegetation.

(5) The open burn emission factors for NOx for orchard and vineyard wood residues are higher than the NOx open burn emission factor for forest wood. When taken with point (1) above, this means that a single NOx emission factor based on a forest vegetation test may be too low if it is also used to represent woody agricultural residues. However, the District's estimated NOx emission factor includes a compliance margin that more than compensates for the potential greater NOx emissions from woody agricultural residues.

Based on the analysis presented in Section 2 above, the District has determined the following emission factors to be appropriately conservative and representative for the burning of woody biomass derived from agricultural sources and forest vegetation in an ACI.

NOx

Only the BC Hydro and Victoria ACI emissions tests reported a NOx emission factor. However, for the reasons discussed in Sections 2D and 2E above, the emission factors derived from those tests appear to be insufficiently conservative when compared to the NOx emission factor for a biomass boiler.

Therefore, the District estimated a more conservative NOx emission factor of 1.0 lb-NOx/ton by multiplying the emission factors reported by BC Hydro and Victoria by a ratio of concentrations. The numerator in this ratio was based on NOx concentration measurements from a 2007 EPA study, Emissions from the Burning of Vegetative Debris in Air Curtain Destructors, J. AWMA, 57, 959-967. This 2007 EPA study did not include measurements of exhaust flow rate or tons of vegetative debris burned; therefore, no emission factors could be derived from the study by itself.

Although the open burn emission factors for NOx for orchard and vineyard residues is higher than the NOx open burn emission factor for forest vegetation by a factor of 1.5 to 1, the District's estimated NOx emission factor is almost 4 times higher than the highest NOx emission factor measured among the potentially representative ACI emissions tests. Therefore, the recommended NOx emission factor provides a sufficient compliance margin to allow for the potential that smaller sized wood pieces from agricultural sources would burn hotter in an ACI, and potentially producing more thermal NOx, than large wood pieces from forest vegetation.

See Attachment C for the derivation of the 1.0 lb-NOx/ton emission factor.

SOx

Since SOx emissions are entirely dependent on the sulfur content of the material burned, the most representative SOx emission factor for an ACI burning woody biomass derived from agricultural sources and forests will be the same as for open burning of those materials, i.e. 0.1 lb-SOx/ton (ARB Memo, "Agricultural Burning Emission Factors," 2000).

PM10

Our current engineering judgement is that PM10 emissions from the combustion of woody biomass in ACIs should be higher than PM10 emissions from a biomass power plant controlled by a fabric filter baghouse. Although there is a growing body of evidence that ACIs are capable of achieving complete combustion with minimal PM10 emissions, to remain conservative when establishing a PM10 emission factor for ACI, the District is recommending the use of the higher PM10 emissions factors derived from the USDA studies in Baker, Oregon and San Bernardino.

The emission factors from the USDA Baker, Oregon (1.15 lb-PM10/ton) and USDA San Bernardino (1.46 lb-PM10/ton) studies are the second and third highest PM emission factors among the full scale ACIs tested, and the only PM emission factors that are lower than the PM10 emission factors for uncontrolled open burning of woody agricultural and forest biomass and higher than the PM10 emission factor for a biomass power plant with fabric filter for PM10 control.

The average PM10 emission factor for the USDA tests is (1.15 lb-PM10/ton + 1.46 lb-PM10/ton)/2 = 1.3 lb-PM10/ton.

Therefore, the 1.3 lb-PM10/ton emission factor derived from the two USDA studies will be accepted as the most representative and conservative PM emission factor for the burning of woody biomass from agricultural sources and forests in an ACI.

CO

As PM10, CO and VOC are all the products of incomplete combustion, acceptance of the PM10 emission factor from the USDA Baker, Oregon study implies an acceptance of the CO emission factor (2.6 lb-CO/ton) as well. The CO emission factor from the San Bernardino study was not included for reasons discussed in Section 2F of this memo. Among the full scale ACIs tested, the Baker, Oregon study produced the median value for a CO emission factor.

VOC

As PM10, CO and VOC are all the products of incomplete combustion, acceptance of the PM10 emission factors from the USDA studies implies acceptance of the VOC emission factors, as well (1.1 lb-VOC/ton and 0.6 lb-VOC/ton, with an average of 0.9 lb-VOC/ton). Among the full scale ACIs tested, the USDA studies produced the highest two emission factors for VOC.

CONCLUSION

Table 3 below summarizes the emission factors selected from the determination above for an ACI burning woody biomass derived from agricultural sources and forest vegetation.

Table 3: Emission Factors for Air Curtain Incinerator Burning Woody Biomass (Agricultural Sources and Forest Vegetation)		
Pollutant	**Emission Factor (lb/ton)**	**Source**
NOx	1.0	SJV Estimation Using/Averaging Data from Multiple Studies, Attachment B
SOx	0.1	ARB Open Burn for Orchard and Vine Crops and Forest Biomass, Table 2
PM10	1.3	Average of USDA Baker, Oregon and USDA San Bernardino Air Curtain Tests, Table 1
CO	2.6	USDA, Baker, Oregon Air Curtain Test, Table 1
VOC	0.9	Average of USDA Baker, Oregon and USDA San Bernardino Air Curtain Tests, Table 1

Please note, as discussed in Section 2F above, the USDA San Bernardino ACI study was not included in the emission factor determination for Authority to Construct (ATC) project N-1162806, for an ACI burning almond sticks at an almond huller. The PM10 and VOC emission factors in that project were 1.1 lb-PM10/ton and 1.1 lb-VOC/ton (based on USDA Baker, Oregon).

Table 4 below includes a wood ash handling emission factor, which is for the combined activities of unloading from a dump truck and spreading coal fly ash at a landfill.

Table 4: Emission Factor for Wood Ash Handling		
Pollutant	**Emission Factor (lb/ton)**	**Source**
PM10	0.23[3]	Fugitive particulate emission factors for dry fly ash disposal, Journal of the Air & Waste Management Association, 63(&): 806-818, 2013

Attachment A: Managing Debris after a Natural Disaster, EPA's Evaluation of Air Curtain Incinerator Emission Source Test Results
Attachment B: Managing Debris after a Natural Disaster, SJVAPCD's Analysis of EPA's Air Curtain Incinerator Study
Attachment C: Derivation of NOx Emission Factor for Air Curtain Incineration of Woody Biomass

[3] The emission factor was reported as 18 g/Mg for PM2.5 and 96 g/Mg for PM10 – PM2.5. Thus, the total PM10 emission factor is 18 g/Mg + 96 g/Mg = 114 g/Mg. 114 g/Mg = 114 lb/10^6 lb × 2,000 lb/1 ton = 0.228 lb-PM10/ton or 0.23 lb-PM10/ton.

Attachment A

Managing Debris after a Natural Disaster: EPA's Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner:

Source Emissions Measurement Results
(November 17, 2016)

[EMBED Package]

Attachment B

Managing Debris after a Natural Disaster: Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner:

SJVAPCD Analysis of EPA's Air Curtain Incinerator Study

Analysis of EPA's Air Curtain Incinerator Study

From:	Brian Clerico, AQE II
To:	Arnaud Marjollet, Director of Permit Services
Reviewed by:	Errol Villegas, Permit Services Manager
Date:	March 10, 2017
Re:	Evaluation of EPA's Air Curtain Incinerator Study: *Managing Debris after a Natural Disaster: Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner: Source Emissions Measurement Results*, November 17, 2016

Background

The District received a draft copy of EPA's *Managing Debris after a Natural Disaster: Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner: Source Emissions Measurement Results*, November 17, 2016 (see **Attachment A**). The study measured emissions and estimated emission factors for an air curtain incinerator (ACI) burning vegetative and construction and demolition debris in 2008 as part of the cleanup from Hurricane Katrina. Three test runs of the emissions from vegetative debris and three test runs for construction and demolition debris were measured separately.

The District's interest in evaluation of this test is in its potential applicability to assessing emissions from Air Curtain Burners that may be employed in and around the San Joaquin Valley to burn vegetative material, such as may be necessary to process over 100 million trees that have died in surrounding forests due to California's recent extreme drought. Therefore, in evaluating the source test results from this EPA study, the District focused solely on the test runs pertaining to vegetative debris.

EPA Air Curtain Incinerator Draft Emission Factors

Table 1 summarizes the emission factors obtained from this study.

Table 1: EPA Emission Factors for Air Curtain Incinerator (Vegetative Debris)		
Pollutant	**Emission Factor (lb/ton)**	**Source**
NOx	1.6	*Managing Debris after a Natural Disaster: Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner: Source Emissions Measurement Result*, Table 5-1 for NOx, SOx, CO, and VOC; Table 5-4 for PM10. See Attachment A
SOx	0.49	
PM10	7.7	
CO	6.9	
VOC	0.41	

Analysis

The District has identified the following concerns with EPA's draft emission factors for vegetative debris:

(1) The vegetative debris in the study is not representative of the types of agricultural or forest wood material in California that would be disposed of in an ACI.

The vegetative debris incinerated consisted of material that had been submerged in brackish water for an unknown amount of time before it was recovered and brought to the test site. Section 3.2.1 Feed Debris from the report describes the vegetative material incinerated as follows:

> *It must be noted that the vegetative debris used for fuel was recovered as part of the Hurricane Katrina response and* ***had sat in brackish water for an unknown period of time prior to being recovered and brought to the test site****. The debris used in the tests therefore was likely representative of much of the vegetative debris recovered during hurricane response activities, where the debris was exposed to salt water for extended periods of time. This uncontrollable variable may have influenced emissions of chlorinated organic compounds including chlorinated benzenes and phenols as well as polychlorinated dibenzo-p-dioxins and polychlorinated furans.*

Given the known dependence of PM10, VOC, CO, and SOx emission factors on the material burned, emission factors derived from vegetative debris soaked in salt water cannot be treated as universally applicable to all biomass materials.

(2) The pollutant mass emission rates are a function of the measured pollutant concentrations multiplied by total flow rate from the air curtain firebox. EPA's calculated flow rates used to derive the pollutant mass emission rates may be overstated by a factor of 3 - 6.

That EPA's calculated flow rates may be overstated can be seen by a comparison of the calculated "slot" (or linear) velocity derived from the calculated flow rates being 3 to 6 times higher than the measured slot velocity for the same make and model ACI operated by EPA burning the same material in a 2007 study

EPA published a 2007 study of limited testing of the Air Burners Model S-327 ACI burning hurricane Katrina vegetative debris in Emissions from the Burning of Vegetative Debris in Air Curtain Destructors, J. AWMA, 57, 959-967. In that study, EPA noted the following:

> *Velocity measurements suggest that the exhaust flow is occurring in a relatively narrow area along the length of the unit on the side opposite the blower (see Figure 5). Measurements of 15 fps [i.e. 15 ft/s] in this narrow area were close to the estimated temperature adjusted flow velocity based on the ACD fan output.*

The "narrow area" referred to above is an 18 inch-wide slot running the length of the ACI. The measured velocity beyond this slot is 0 f/s, meaning all the exhaust exits the firebox along this slot opposite the blower. This is a finding corroborated by other ACI studies. The 15 ft/s appears to be an average slot velocity measurement, uncorrected for temperature, although the exact temperature corresponding to this velocity is unclear.

EPA did not perform velocity measurements in the draft ACI emission factor study; however, EPA did make use of the findings from the 2007 study to design their sample collection scoop for the ACI emission factor study:

> *The entry face of the extraction scoop was 18 inches by 5 inches, with the longer dimension spanning the final 18 inches of the ACB firebox width on the side opposite the blower plenum as shown in Figure 2-2. This 18-inch span along the length of the ACB represents the area where, from earlier flow determinations on an identical burner, essentially all the combustion product gases exit the firebox. With this experience in mind, and the earlier measurement of 15 ft/sec bulk velocity in that 18-inch span, estimated extraction scoop isokinetic variation during the sampling runs was calculated. During the test program, isokinetic variation was between 47.8% and 90.9%, with an average of 65.9%.[Section 3.2.3]*

Using the calculated flow rates from the emission factor study, an average slot velocity can be calculated. EPA's calculated flow rates from the firebox are based on a mass balance calculation of carbon (Section 3.4 of the EPA report in Attachment A). Taking the average calculated flow rates from Table 3-2 of the report (104,147 dscfm) and dividing by the area of the slot (27 feet by 1.5 feet), yields and average slot velocity of 43 ft/s at 68 °F, or 94 ft/s at 700 °F (average scoop temperature along the slot). Since the slot velocity is directly proportional to the average volumetric flow rate, if the volumetric flow is overstated by a factor of 3 (43 ft/s ÷ 15 ft/s) to 6 (94 ft/s ÷ 15 ft/s), then so too will be the emission factors, which are based on the calculated flow rates.

One possible objection to this comparison of the calculated versus the measured slot velocities would be that we do not know the feed rate to the ACI when the velocity measurements were made in the EPA 2007 study. If the feed rates during the slot velocity measurements in the 2007 study were low in comparison to the feed rates during the emission measurements in the emission factor study, then the claim above is not valid. We do know, however, that during the emission factor study, the feed rates to the ACI were reported as 4.8 ton/hr, 4.8 ton/hr and 6.8 ton/hr. Air Burners Model S-327 ACI has a capacity of 6-10 tons/hr. Thus, the feed rates to the ACI during the emission factor study were either below the rated capacity of the unit or on the low side. It seems unlikely during the 2007 study, EPA would have operated the ACI at a feed rate 3 to 6 times lower, i.e. 1 – 2 ton/hr, to account for the observed difference in the measured to the calculated velocities.

(3) The high SOx emission factor suggests a possible overstatement of all the emission factors by a factor of 4 - 5.

The draft SOx emission factor (0.49 lb/ton) is more than twice the next highest reported emission factor for an ACI and almost five times the open burn value for almonds or forest material.

Since SOx emissions are purely a function of the sulfur content of the material burned, the high SOx emission factor could be another indicator that the emission factors are high across the board by a factor of four to five because of EPA's flow rate calculation estimation procedure above. An alternative explanation for the high sulfur is that the wood burned could have a considerable amount of sulfur contamination from being submerged in brackish water for an unknown amount of time; however, this could raise concerns of the representativeness of the emission factors for material not subjected to the same conditions.

On the other hand, when coupled with concern number 2, above, the weight of evidence starts to lead to a conclusion that the emissions factors are significantly overestimated.

The following concerns relate specifically to EPA's particulate matter (PM10) emission factor.

(4) EPA's proposed PM10 emission factor is greater than the currently accepted emission factor for open burning of almond wood as well as many other agricultural materials.

The emission factors for open burning of almond wood (6 lb-PM/ton, AP-42, Table 2.5-5; or 7.0 lb-PM10/ton, ARB Memo, "Agricultural Burning Emission Factors," August 17, 2000) are lower than EPA's proposed air curtain emission factor (7.7 lb-PM10/ton). For the same material burned, we believe all parties should agree that the PM10 emission factor for the ACI should be significantly lower than the emission factor for open burning. At a minimum, this suggests that EPA's proposed emission factor cannot be universally applied to all wood materials.

When considered in conjunction with concerns 2 and 3 above, and the expectation of actual control of PM10 emissions when comparing ACI to open burning (prior tests demonstrated a control efficiency of 54% to 99+%), the weight of evidence continues to grow that emissions estimates from this study are likely and significantly overstated.

(5) The hurricane occurred in August 2005, whereas the vegetative debris was retrieved and tested in June 2008. Thus vegetative debris/wood may have been submerged in brackish water for up to three years prior to being sent to the air curtain for incineration. The salt water likely left a residue of salts (i.e. inorganic species) precipitated on and in the wood, which would increase the measured PM concentrations. Possible effect on PM10 EF: 30% too high.

The PM fraction contained a relatively high amount of inorganic condensable PM (EPA report, Table 5 – 4: 38% weighted average; 51% in Run 1 and 26% in Run 2, Run 3 not reported). The report noted a variety of chlorinated organics found in the air toxics analysis. The predominant anionic species in salt water is chloride ion, which could be the source of the elemental chlorine in the chlorinated organics observed. Wood is porous, so salts containing chloride ion could infiltrate and precipitate on the wood over time. The presence of salts in combustion processes are known to produce condensable PM, which can be seen in detached white plumes. This phenomenon would be consistent with the opacities recorded in this study, which were higher than in other air curtain tests: e.g. Run 3 failed opacity (using NSPS Subpart EEEE standard). One potential cause for higher opacity could be associated with overloading the air curtain firebox; however, the higher opacities cannot be due to overloading because according to Air Burners Inc., the model air curtain has a capacity of 6-10 tons/hour, but in the Katrina study, it was fed at an average rate of 4.8 tons/hr.

Additionally, for open burning, wet wood is known to produce more smoke than dry wood. According to the moisture analysis EPA performed on the vegetative debris burned, the water content was not more than 30%, which is similar to "green" wood. In conversation with District staff, Air Burners, Inc. has claimed that the ACI should be able to burn green wood and maintain compliance with NSPS visible emission limits of 10% opacity or less. As a reference, District Rule 4901, Wood Burning Fireplaces and Wood Burning Heaters, which is a PM rule, prohibits the sale of wood having greater than 20% moisture. For comparison, the average moisture content of almond tree derived biomass = 18% according to the ARB agricultural burning emission factors memo.

(6) The average isokinetic variation (ratio of $Velocity_{sample}/Velocity_{"stack"}$) was 65.9%. Estimated effect on PM10 EF: 10%+ too high.

A low isokinetic % means the measured PM value is higher than the actual PM value (https://www.arb.ca.gov/testmeth/vol1/vol1suppl.doc). 90 – 110% (or under some conditions 80 – 120%) is the normal acceptable quality control range. The magnitude of error depends on a number of variables, especially particle size distribution. EPA characterizes the overestimation error from anisokinetic sampling

conditions in the Katrina study as "slight" perhaps because the PM emission factor appears to be predominantly composed of PM2.5. However, in ARB's Supplement to Stationary Source Test Methods, Volume 1, Chaper IX, pg. 6), an example is given of a study where an isokinetic variation of 50% represented an 80% over-estimate of the PM12 emissions. On the Fountainhead test, a similar sized unit to the unit used in the EPA study, the reported average isokinetic variation was 112%, which would lead one to believe that the reported Fountainhead emission factor was on the low side, but also that isokinetic sampling is achievable with such as source.

From page 90 (pg 106 .pdf) of EPA's report, *"If isokinetic rate calculations are based upon the estimated total flow rates presented in Table 5-1[4], variation was between 6.1% and 46.5% isokinetic."* Meaning if EPA's calculated flow is 100% correct, then the isokinetic variation (#1) is dramatically worse than the 65.9%. The bias to a higher PM rate grows exponentially higher at lower isokinetic percentages.

Conclusion

Based on the analysis presented above, the District concludes that the weight of evidence suggests that emission factors from EPA's study *Managing Debris after a Natural Disaster: Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner: Source Emissions Measurement Results* (November 17, 2016) are likely overstated and cannot be found to be representative of the emissions from incineration of vegetative materials.

Therefore, the results of this test are not recommended to be used in future permitting actions for air curtain incinerators in the District.

[4] This may be a typographical error as volumetric flow rates are presented in Table 3-2, whereas Table 5-1 present mass emission rates.

Attachment C

Derivation of NOx Emission Factor for Air Curtain Incineration of Woody Biomass

NOx Emission Factor Estimation

There are two published source tests on ACIs where NOx emission factors were derived: BC Hydro (0.040 lb-NOx/ton) and Victoria, Australia (0.274 lb-NOx/ton). These values are significantly lower than the biomass power plant NOx emissions, which is equipped with NOx control selective non-catalytic reduction system).

EPA published NO and NO_2 concentration measurements (ppmv) from an ACI burning vegetative debris in a 2007 study, Emissions from the Burning of Vegetative Debris in Air Curtain Destructors, J. AWMA, 57, 959-967; however, no emission factor (lb-NOx/ton material burned) was published or derived from the data because no flow rates or material throughputs corresponding to the measured concentrations were measured or published. This 2007 EPA study measured an average NOx (NO + NO_2) concentration of 79 ppmv from the air curtain, which is higher than the NOx concentration measurements from the BC Hydro (3.4 ppmv) and Victoria, Australia (19.5 ppmv) tests. Assuming the NOx emission factor that could be derived from the 2007 EPA test data will be proportional to its NOx concentration, following ratio will be used:

$$\left(\frac{lb-NOx}{ton}\right)_{EPA\,(2007)} = \left(\frac{lb-NOx}{ton}\right)_{Source\ Test\ X} \times \frac{(ppmv\ NOx)_{EPA\,(2007)}}{(ppmv\ NOx)_{Source\ Test\ X}}$$

Source Test X = BC Hydro

The NOx emission factor from the BC Hydro test was 0.040 lb-NOx/ton.[5] The average NOx concentration measured during the BC Hydro test was 6.5 mg/m^3 (at 20 °C). The molar volume of an ideal gas at 20°C is 24.1 × 10^{-3} m^3/g-mol.

$$6.5\ \frac{mg\ NO_x}{m^3(at\ 20^0C)} \times \frac{1\ g\ mol\ NO_2}{46\ g\ NO_2} \times \frac{1\ g}{1{,}000\ mg} \times \frac{24.1 \times 10^{-3}\ m^3\ (at\ 20^0C)}{1\ g\ mol} = 3.4\ ppmv\ NO_x$$

$$\left(\frac{lb-NOx}{ton}\right)_{EPA\,(2007)} = \left(\frac{0.040\ lb-NOx}{ton}\right)_{BC\ Hydro} \times \frac{(79\ ppmv\ NOx)_{EPA\,(2007)}}{(3.4\ ppmv\ NOx)_{BC\ Hydro}}$$

$$\left(\frac{lb-NOx}{ton}\right)_{KEPA\,(2007)} = \frac{0.93\ lb-NOx}{ton}$$

[5] Based on an emission rate of 0.12 kg-NO_2/hr and 6 metric tonnes feed/hr
EF = 0.12 kg/hr x 2.2 lb/kg x 1 hr/6 tonne x 1 tonne/1.1 tons = 0.040 lb-NOx/ton

Source Test X = Victoria, Australia

The NOx emission factor from the Victoria test was 0.247 lb-NOx/ton. The average NOx concentration measured during the Victoria test was 40.0 mg/Nm^3 (i.e. at 0 ˚C). The molar volume of an ideal gas at 0ºC is 22.4 × 10^{-3} m^3/g-mol.

$$40.0\ \frac{mg\ NO_2}{Nm^3} \times \frac{1\ g\ mol\ NO_2}{46\ g\ NO_2} \times \frac{1\ g}{1{,}000\ mg} \times \frac{22.4 \times 10^{-3}\ Nm^3}{1\ g\ mol} = 19.5\ ppmv\ NO_x$$

$$\left(\frac{lb - NOx}{ton}\right)_{EPA\,(2007)} = \left(\frac{0.274\ lb - NOx}{ton}\right)_{Australia} \times \frac{(79\ ppmv\ NOx)_{EPA\,(2007)}}{(19.5\ ppmv\ NOx)_{Australia}}$$

$$\left(\frac{lb - NOx}{ton}\right)_{EPA\,(2007)} = \frac{1.1\ lb - NOx}{ton}$$

Average NOx Emission Factor

Average NOx emission factor (lb/ton) = (0.93 lb-NOx/ton + 1.1 lb-NOx/ton) ÷ 2

Average NOx emission factor (lb/ton) = 1.0 lb-NOx/ton